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Disposal of Flue-Gas-Cleaning Wastes

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16. ABSTRACT The article describes current commercial and emerging technology for disposal of wastes from flue gas cleaning (FGC) systems for coal-fired power plants. Over 80 million metric tons/yr (dry) of coal ash and desulfurization solids are expected to be produced by the 1980's. Although opportunities for utilization of these wastes will exist at many plants, disposal is expect to be the most common practice. Several disposal methods are being studied to minimize adverse environmental effects from disposal of FGC wastes. These include ponding, landfill disposal, mine disposal, and at-sea disposal. Ponding and landfill disposal are both current practices; environmental and economic improvements of these methods are emerging through a combination of EPA and private industry efforts. Disposal in mines, particularly coal mines, appears quite promising, and is being strongly considered by several electric utilities. At-sea disposal is currently under study and, although a degree of uncertainty exists regarding its viability, several approaches appear promising.		
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Disposal of flue-gas-cleaning wastes



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The projected increase in use of coal for power will byproduce large quantities of ash and sulfur compounds from the cleaning of flue gases. Here is a summary of current technology for disposing of those byproducts.*

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□ Coal-burning power plants in the U.S. produce large quantities of wastes that accumulate in ash-collection devices or flue-gas desulfurization (FGD) systems. Since coal use is being encouraged, and since FGD systems are often necessary to reduce sulfur oxide emissions, the rate of coal-ash and FGD-waste production is expected to grow rapidly.

Coal-ash production by electric utilities is expected to reach 65 million metric tons/yr, including over 45 million metric tons of fly ash, by 1980[1]. U.S. electric-utility commitments to FGD currently total 46,425 MW of electrical generating capacity[2]. Assuming

* Mention of tradenames, commercial products, or commercial processes does not constitute endorsement or recommendation for use.

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** In Great Britain, the Central Electric Generating Board (CEGB) for at least the past ten years has produced and marketed the bulk of 10-11 million metric tons of coal ash annually[3]. In Japan, over 1 million metric tons of gypsum were made, primarily for use in wallboard and portland cement, by FGD processes in 1975[4].

that all of these plants will burn a typical high-sulfur Eastern coal and use limestone scrubbing, approximately 24 million metric tons/yr (dry) of waste will be produced by 1985, when all these committed plants are onstream.

Although extensive utilization of coal ash and FGD waste is practiced elsewhere,** less than 20% of the coal ash produced in the U.S. is currently used[1], and there have been no full-scale commitments by U.S. utilities to produce FGD gypsum for sale. This situation may change because of technological innovations or overriding economic concerns. However, since disposal is the most attractive choice for many utilities, the environmental, technological and economic effects of various disposal options will have to be addressed.

Disposal of coal ash, either by ponding or landfill, has been practiced in the U.S. for many years, and ash ponds at power plants overflow to rivers in many locations. Until recently, such practice was not of major environmental concern, probably because of the rela-

Projects in FGC Waste and Water Program Table I

Project title	Contractor/agency
FGC Waste Characterization, Disposal Evaluation, and Transfer of FGC Waste Disposal Technology*	The Aerospace Corp.
Lab and Field Evaluation of 1st and 2nd Generation FGC Waste Treatment Processes	U.S. Army Corps of Engineers Waterways Experiment Station
Characterization of Effluents from Coal-Fired Power Plants (Waste and Water Only)	Tennessee Valley Authority
Ash Characterization and Disposal	Tennessee Valley Authority
Studies of Attenuation of FGC Waste Leachate by Soils	U.S. Army Material Command Dugway Proving Ground
Establishment of Data Base for FGC Waste Disposal Standards Development	Stearns, Conrad and Schmidt Consulting Engineers, Inc. (SCS Engineers)
Shawnee FGD Waste Disposal Field Evaluation*	Tennessee Valley Authority; The Aerospace Corp.
Louisville Gas and Electric Co. Evaluation of FGD Waste Disposal Options	Louisville Gas & Electric Co. (Subcontractor: Combustion Engineering)
FGD Waste Leachate-Liner Compatibility Studies	U.S. Army Corps of Engineers Waterways Experiment Station
Lime/Limestone Wet Scrubbing Waste Characterization	Tennessee Valley Authority
Dewatering Principles and Equipment Design Studies	Auburn University
Conceptual Design/Cost Study of Alternative Methods of Lime/Limestone Scrubbing Waste Disposal	Tennessee Valley Authority
Gypsum By-Product Marketing Studies	Tennessee Valley Authority
Evaluation of Alternative FGD Waste Disposal Sites*	Arthur D. Little, Inc.
Lime/Limestone Scrubbing Waste Conversion Pilot Studies	M.W. Kellogg Co.
Fertilizer Production Using Lime/Limestone Scrubbing Wastes	Tennessee Valley Authority
Use of FGD Gypsum in Portland Cement Manufacture	S.C. Public Service Authority; Babcock & Wilcox; Santee Portland Cement
FGD Waste/Fly Ash Beneficiation Studies	TRW, Inc.
Assess/Demonstrate Power Plant Reuse/Recycle	Radian Corp.

*Projects discussed in this paper

tively low solubility of the chief chemical constituents in most coal ashes. However, from the time that FGD systems were introduced, there was major concern about disposal of the wastes or "sludges," because of: the large amount of occluded water in these wastes; the wastes' quite variable physical and chemical properties; and the soluble and slightly soluble constituents in the water.

As a result of this concern, considerable research and development has been undertaken by governmental and private organizations. The major thrust of these efforts has centered on FGD wastes. However, since such wastes contain varying amounts of fly ash, depending on whether the ash is collected separately or simultaneously with the sulfur oxides in the flue gas, any study

of FGD waste disposal also involves disposal of the associated ash.

Studies of ash disposal alone have been undertaken by the U.S. Environmental Protection Agency[5] (EPA) and the Electric Power Research Institute[6] (EPRI); and the Tennessee Valley Authority (TVA) is currently conducting additional studies under EPA sponsorship[7]. This article will not address these studies, but will rather be limited to studies for the disposal of FGD wastes. Since these wastes do contain some fly ash, they will hereafter be referred to as FGC (flue gas cleaning) wastes.

Current FGC waste-disposal practices

Most of the U.S. utility companies' installations of nonregenerable (e.g., lime/limestone) scrubbing systems have used disposal methods similar to those for ash disposal—e.g., ponding. The earliest systems employed unlined disposal ponds, but because of concerns about possible effects on groundwater quality, low-permeability clay-lined ponds have been provided at some of the more recent installations. In addition, chemical treatment (fixation) of the FGC wastes has been chosen by some utility companies because of (1) expected improvement in structural properties and (2) resistance to leaching [8].

Federal regulations or guidelines for disposal of FGC wastes have not yet been issued. However, the Federal Water Pollution Control Act Amendments of 1972 and the Safe Drinking Water Act of 1974 both indicate that the desire of Congress is to eliminate or minimize chemical pollutant discharges into surface waters and groundwaters[9]. In addition, the Resource Conservation and Recovery Act of 1976, signed into law last October, now requires EPA to establish regulations or guidelines for disposal of wastes from air pollution control devices[10].

Recognizing the need for better definition of approaches to meet this legislative challenge, EPA in 1972 initiated a major program of research and development in the area of FGC waste disposal, as a follow-on to modest efforts initiated in the late 1960s in support of the limestone scrubbing program. The primary objectives of the 1972 program were to better quantify any potential environmental problems associated with FGC waste disposal, to assess current FGC waste-disposal technologies, and to recommend alternate disposal approaches.

Initial efforts under the program indicated that disposal techniques that minimized or eliminated the potential for water pollution were required. At that time, the best available techniques were landfilling of chemically fixed FGC waste, or disposal of untreated waste in ponds lined with low-permeability clay, or plastic or rubber. Detailed results of this program have been described[11,12].

Current EPA R&D

In late 1974, plans were formulated to greatly expand the R&D on FGC waste as part of EPA's Energy Research Program. These efforts included improved quantification of environmental parameters and were also aimed at reducing costs, investigating a broader

range of alternative disposal strategies, and encouraging byproduct usage. The program, entitled "FGC Waste and Water Program," currently consists of the 19 projects listed in Table 1. Of these, three ongoing projects* have produced most of the results summarized below.

Pond disposal of FGC wastes

Historically, the most frequently used alternative for disposal of FGC wastes (including coal ash) has been ponding. In most cases, the slurried solids are pumped. The slurry comes either from the bottom outlet of a clarifier or directly from the scrubber, with the pond acting as the settler/clarifier. Clarified liquor is normally returned to the scrubber system.

Two major environmental considerations are inherent to ponding FGC wastes: (1) the water-pollution potential of soluble materials, and (2) the land-degradation potential of nonsettling, or physically unstable, waste solids.

The water pollution potential of FGC wastes is primarily dependent on the chemical properties of the wastes but is also affected by the physical properties (e.g., permeability) that affect the rate of leachate generation. These properties vary widely for different power-plant and scrubber operations; important variables include the sulfur and ash content of the coal, the type of scrubber system (lime, limestone, dual alkali), the amount of unreacted alkali in the waste, the amount of ash in the waste, the degree of dewatering of the waste, and the degree of oxidation of sulfites to sulfates. Pollution potential can be attributed to soluble trace metals, chemical oxygen demand (COD) from the sulfites, excessive total dissolved solids (TDS), and excessive levels of other major chemical species (sulfate, chloride, calcium, magnesium, sodium).

An example of the pollution potential from ponding untreated FGC wastes is shown in Table II, which compares some of the results of leachate analyses from EPA field-disposal tests [13] (currently underway) with the EPA proposed National Interim Drinking Water Regulations[14] and the 1962 U.S. Public Health Service Drinking Water Standards, both conservative criteria.

The concentrations in these analyses come very near to the maximum observed in the leachate from untreated wastes of the pond and, as expected, reflect the concentrations of the constituents in the raw waste liquor. After reaching these maximums, these concentrations have tended to diminish, indicating a flushing out of the solubles in the waste. Laboratory data have shown essentially complete flushing of solubles after five pore-volumes of leachate have been generated[15]. The long-range pollution potential, after this initial flushing takes place, is represented primarily by the solubility of calcium sulfate (gypsum). This indicates that some form of control must be considered to limit

* (1) FGC-Waste Characterization, Disposal Evaluation, and Transfer of FGC-Waste-Disposal Technology (the Aerospace Corp.)
(2) Shawnee FGD Waste Disposal Field Evaluation (TVA/The Aerospace Corp.)
(3) Evaluation of Alternative FGD Waste Disposal Sites (A.D. Little, Inc.)

The TVA and Aerospace Corp. efforts in the first two projects address primarily ponding and landfill of FGC wastes; the A.D. Little efforts focus primarily on the feasibility of mine and ocean disposal.

Comparing leachate with drinking water

Table II

Constituent	Selected pond a* leachate analyses, mg/l	National interim drinking water regulations, mg/l	1962 U.S. public health service drinking water standards, mg/l
Arsenic	0.08	0.05	0.05
Mercury	0.0067	0.002	0.002
Selenium	0.013	0.01	0.01
Lead	0.062	0.05	0.05
Sulfate	980	—	250
Chloride	3,500	—	250

* Contains untreated wastes from a lime-scrubbing FGD system

the entry of major species and trace elements into public water supplies.

If selected properly, the composition of the bottom and sides (or dikes) of a pond can reduce the pollution potential of FGC wastes by (1) attenuating the pollutant migration into the ground via ion exchange or adsorption, and/or (2) greatly reducing the rate of pollutant migration because of very low permeability (e.g., 10^{-6} cm/s). Such bottoms and sides may consist of the naturally occurring soil that makes up the disposal site, or of a natural liner material, such as placed and compacted clay, or of a synthetic liner. Although impermeable linings can alleviate the pollution potential of the operating FGC waste pond, the retention of water is of concern in reclaiming the disposal site when the pond is retired.

Physical instability of untreated FGC wastes is primarily caused by small platelet or needle-like crystals of calcium sulfite hemihydrate, which settle very slowly and trap water even when filtered. Pond-settling untreated sulfite-rich FGC waste solids typically results in a concentrated slurry of less than 50% solids[9]. At this concentration, these wastes exhibit "thixotropic" behavior†, so that dewatering to about 65-70% solids is necessary in most cases to achieve physical stability, and optimum compaction is achieved at about 80% solids[16]. Several approaches (e.g., vacuum filtration) may be taken to increase the final percentage of solids to greater than 50%.

However, typical FGC wastes are generally very difficult to pump at greater than 50% solids[17]. Since the pond is used as the primary dewatering mechanism, only those approaches that would greatly improve the settling properties of the solids are applicable. Examples include: process modifications to increase the size of the sulfite crystals, oxidation to produce gypsum,** and chemical treatment (e.g., the Dravo Corp. proprietary Synearth process).

Decreasing the moisture in FGC wastes can make possible future reclamation of the pond. However, if a hydraulic head, created by decanted waste liquor plus rainwater, is permitted to remain indefinitely on top of

† FGC wastes are not truly thixotropic materials, the viscosity of which depends not only on the rate of shear but the time over which the shear force is applied (i.e., they become stable again after the shear force is removed); FGC wastes generally remain "liquified" once rendered to that state, unless further dewatered.

** FGC wastes from low-sulfur Western coal-fired plants primarily contain gypsum as the reaction product.

the wastes, soluble constituents will be forced into the ground water below, if the pond is not reclaimed.

Ponding costs can vary considerably, depending on the technical design of the disposal system and on site-specific factors such as labor costs and costs for delivery of liner materials. Preliminary estimates by The Aerospace Corp. have indicated ponding costs varying from \$5.50 to \$10 per metric ton of dry solids, excluding pond reclamation costs[16].

Landfill disposal of FGC wastes

Coal ash has generally been disposed of as landfill, where ponding is impractical. Although landfill disposal has also occurred with FGC wastes (e.g., at Duquesne Light Co.'s Phillips Station), the primary motive has been to avoid the land-deterioration and water-pollution problems associated with ponding.

For landfill disposal, dewatered or treated FGC wastes are hauled to the disposal site, or waste slurries are pumped to the site for dewatering or treatment there. The dewatered wastes are placed and compacted. Although sanitary landfill procedures (i.e., daily covering) are not necessary, exposure to rainfall should be at a minimum so as to reduce leaching and (in the case of untreated wastes) possible reslurrying. The disposal site should be designed so that a minimum of runoff water enters it. Since some runoff will probably be generated around the site, trenches for collection and recycle or treatment should be provided.

Finally, FGC wastes must have enough physical stability to be handled by earth-moving equipment for landfill disposal. This means dewatering the material to at least 50% solids and possibly as high as 65-70% solids by mechanical, thermal[9] or chemical means, or a combination of these.

There are four methods for improving dewatering: (1) adding dry solids, (2) improving the dewatering equipment, (3) controlling crystal size, and (4) oxidizing to obtain gypsum. They follow approximately that order of increasing complexity. (The above statement applies to medium- and high-sulfur applications; FGC wastes from low-sulfur Western-coal-fired plants primarily contain gypsum as the reaction product.)

One of the easiest ways to dewater FGC wastes is by adding dry solids, such as fly ash. Gravity settling followed by vacuum filtration results in a maximum of only 50-60% solids with many FGC wastes; but if an equivalent amount of dry fly ash is added to a 55% solids material, an increase to about 70% solids is obtained.

Another approach improves the gravity-settling equipment so that it can produce 65-70% solids after vacuum filtration. This possibility is being examined in an EPA-sponsored study at Auburn University (Grant No. R804531-01-0), where improved gravity-settler design studies, as well as filtration and pumpability tests, will be conducted.

Another approach increases the size of calcium sulfite hemihydrate crystals. Radian Corp. has developed a process (patents applied for) that controls crystal size through the use of mechanical equipment in conjunction with lime/limestone scrubbing.

One outgrowth of such scrubbing is strong evidence

that dual-alkali technology offers another approach through which crystal size can be controlled. In this case, solids are produced in a special reactor outside the scrubber loop[18].

Increasing the reaction-product crystal size is also one of the purposes of oxidizing FGC waste to gypsum, since gypsum crystals are typically much larger and thicker than sulfite crystals, and therefore settle quicker and trap less water.

Still another way to "dewater" FGC wastes is by one of several proprietary chemical-treatment or "fixation" processes offered by firms such as IU Conversion Systems, Inc., Dravo Corp., and Chemfix, Inc. Whereas all these companies' processes are designed to produce a physically stable material with reduced solubility, the processes and products are quite different. Each has treated FGC wastes from large (10 MW equivalent) EPA lime/limestone pilot scrubbers at TVA's Shawnee Steam Plant. Preliminary results from field disposal tests on the treated materials have recently been reported[13,15].

In general, the results show physical stability, greatly increased compressive strength, lower permeability, and about 50% lower concentrations of major solubles* (e.g., chloride and sulfate) in the leachate, when compared to untreated wastes from the same pilot scrubbers. Total costs for treatment and disposal of the Shawnee-type waste (high-sulfur coal, fly ash collected in the scrubber) were estimated at \$8.10-\$12.70 per (dry) metric ton of waste[13,15].

Mine disposal of FGC wastes

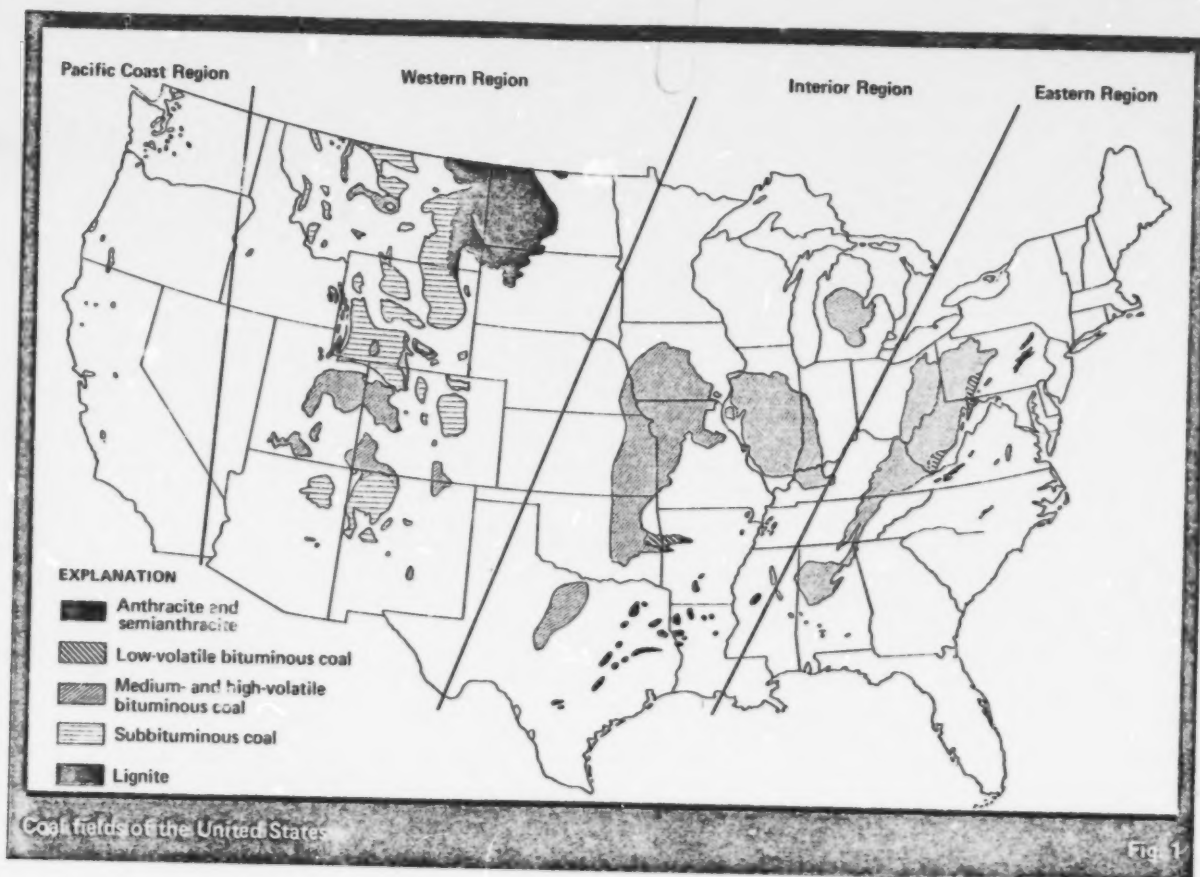
The concept of coal-mine disposal of FGC waste has greatly interested engineers in the flue-gas-desulfurization industry for many years. The attraction was created by the existence of railroad transportation between the coal mine and the power plant, and the need for material to fill the void left by mining of the coal. In addition, many plants may not have sufficient land area for on-site disposal.

However, studies for disposal of FGC waste in mines (e.g., the U.S. Bureau of Mines Contract S0144135 with Radian Corp. to examine the use of these wastes to prevent underground coal-mine subsidence, and the current EPA Contract 68-03-2334 with Arthur D. Little, Inc.) have only recently been undertaken.

The contract with A. D. Little is designed in part to assess the technical, environmental and economic factors associated with mine disposal of FGC wastes through engineering studies as well as laboratory and pilot-scale experiments. The preliminary assessment phase of the effort has essentially been completed, and some initial conclusions are possible.

An initial review identifies four general categories of mines as the most promising candidates: active surface-area coal mines; active underground coal mines; inactive or mined-out portions of lead/zinc mines; and inactive or mined-out portions of active underground limestone mines. Each category was reviewed with regard to: the alternatives for placement; the physical properties of FGC wastes that would be suitable; the

* Trace-element concentrations have not consistently shown a comparable decrease.



environmental/technical (e.g., operational) impacts; the capacities; and the availability and accessibility (via transportation systems) for FGC waste disposal. As a result of this review, the following mines were determined most promising:

1. Active Interior* surface-area coal mines.
2. Active Eastern* and Interior* room-and-pillar underground coal mines.

In general, Interior surface-area coal mines appear to be more promising than Western (Rocky Mountain and Pacific Coast) surface-area coal mines. However, surface-area mines both in the Interior and the West were considered much more promising than Eastern surface contour mines, because of the latter's low capacity for FGC wastes and the difficulty for waste placement. The problem with the Western surface-area mines is the greater potential for groundwater contamination, relative to Interior mines, because of a lower net annual rainfall, resulting in less dilution of leachate. In addition, FGC wastes from Western plants burning low-sulfur coal normally contain a higher concentration of dissolved salts.

Individual Interior surface-area mines have substantial capacity for receiving FGC wastes, and disposal is considered technically feasible within existing mining operations. The wastes must be dewatered to the extent necessary for landfill operations, so that they can be

* Refers to one of four U.S. "provinces" in which coal fields occur i.e., Eastern (including Appalachia), Interior (between Rocky Mountains and Appalachia), Rocky Mountain, and Pacific Coast.

dumped into a mined-out strip (which can be adjacent to one being mined) and covered with overburden. Placing FGC waste in the mine void should assist in returning the terrain to its original elevation.

The principal environmental impact anticipated from this disposal method is an increase in total dissolved solids (TDS) in waters that are recharged by leachate from the disposal site. This impact may be lessened by placing part of the overburden in the mined-out strip prior to placing the FGC waste, thereby elevating the waste above the groundwater table. In addition, dilution to acceptable TDS levels can be encouraged by maintaining a suitable distance between the disposal site and the nearest stream, or by assuring that the receiving streams have a sufficiently high flowrate. Although more expensive, chemical treatment of the FGC wastes should also lower the TDS level in the leachate, as well as reduce the quantity of leachate, because of a lower permeability of the treated material.

Disposal of FGC wastes in a surface lignite mine is currently planned for Unit 2 of the Milton R. Young Station of Minnkota Power Cooperative in Center, N.D. [19], which will generate about 450 MW at full load. The flue gas will be scrubbed using alkaline ash (collected by the electrostatic precipitators of Units 1 and 2) as the absorbent. Disposal of treated FGC wastes in a local surface mine was originally considered by an Ohio utility for two new 400-MW units, but was dropped in favor of a disposal site available closer to

the power plant[20]. A Montana utility also considered surface mine disposal of FGC wastes, but decided to use a settling pond closer to the plant.[21] Other units planned for this plant may cause reconsideration of the surface mine[18].

Among the underground mines studied, Eastern and Interior coal mines using conventional room-and-pillar methods were determined to be promising. Mined-out portions of room-and-pillar mines can be bulkheaded and filled with FGC waste by pumping it down from the surface through holes in the roof of the mine. Since long-wall mining involves roof-collapse in the mined-out area, placing FGC waste could substantially complicate the mining operation.

Placement of either treated or untreated FGC wastes in room-and-pillar underground mines can reduce their acid drainage to groundwater, since filling the voids in these mines would reduce oxidation of pyritic sulfur and the formation of acid. Residual calcium carbonate in the FGC wastes would also partially neutralize existing acid.

In addition to these benefits, certain treated wastes could reduce long-term subsidence of the room-and-pillar mines by providing lateral pillar and roof support. However, untreated wastes, on the other hand, would not be expected to provide sufficient strength for subsidence control unless substantial settling of the solids (to about 65-70% solids) occurred after placement.

Contamination of groundwater in the mine would be most likely to occur if untreated FGC wastes were used. The water quality of nearby streams would be affected also. Such effects must be viewed relative to the amount of dilution and/or soil attenuation anticipated between the mine and the stream, as well as relative to the alternative of acid mine drainage (in the case where FGC wastes are not placed) affecting the stream quality. In other words, use of room-and-pillar coal mines for FGC waste disposal must be decided according to the hydrogeology of the site.

Underground room-and-pillar lead/zinc mines in the U.S. interior possess vast capacity for FGC waste disposal; both active and inactive mines appear feasible from operational and capacity standpoints. However, they are not linked to electric utilities by a transportation system, so the economics of FGC disposal in lead/zinc mines are probably not favorable. However, underground room-and-pillar limestone mines in the U.S. interior that are located above the water table appear to be feasible sites for FGC waste disposal from a technical and environmental standpoint. Still, these dry mines are limited in number and capacity and may be viable in only a few situations.

Ocean disposal of FGC wastes

Ocean disposal of various types of wastes has been taking place for many years. With increasing awareness of the adverse effects of much of this activity, recent efforts have been undertaken to reverse the degradation of the ocean environment. The Marine Protection Research and Sanctuaries Act of 1972 (PL92-532) is the major federal legislative action in this area. Section 2(b) of the Act states, "The Congress declares that it is the policy of the United States to regulate the dumping

Chemical treatment of FGC wastes has shown physical stability, greatly increased compressive strength, lower permeability, and about 50% lower concentrations of major solubles (e.g., chloride and sulfate) in the leachate, when compared to untreated wastes.

of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material that would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." [Italics are author's.]

The italicized portion of the quotation represents one of the major criteria by which methods for the ocean disposal of FGC wastes are being judged in the Arthur D. Little, Inc. studies for EPA. These studies were undertaken because it was apparent that if ocean disposal of FGC wastes proved environmentally acceptable, power plants currently burning low-sulfur oil in the northeastern U.S. could switch to high-sulfur coal. Many plants in the Northeast cannot presently burn coal because of a lack of land-based FGC-waste disposal sites; however, many of these plants do have access to the ocean. Another reason for undertaking the studies was the recognition that the major chemical constituents in FGC waste (i.e., chlorides, sulfates, calcium) are found in relatively high concentrations in seawater, so that the impact of adding these constituents would probably not be very significant.

An examination of the physical and chemical characteristics of FGC wastes has identified the following environmental concerns relating to ocean disposal:

1. Ocean-floor sedimentation—The particle (crystal) sizes of most untreated FGC wastes are much smaller than the coarse-grained sand particles of the ocean floor, which are most conducive to the marine life found on the Continental Shelf. Therefore, deposition of these wastes in large quantities may have an undesirable effect in the relatively shallow Continental Shelf area, particularly if disposal results in "paving" of the ocean floor.

2. Solids suspended in the water column—Settling of disposed FGC wastes toward the ocean floor through the water column, as well as resuspension of solids from the ocean floor, would expose various types of marine life to elevated concentrations of suspended sediments. The effects of sediments vary from minimal to serious, depending on the organism involved.

3. Sulfite-rich wastes—Many FGC wastes contain significant quantities of calcium sulfite hemihydrate, presenting a potential problem of sulfite toxicity to marine life and a potential chemical oxygen demand (COD) problem if oxidation to sulfate occurs. The sulfite toxicity depends on the degree of waste ingestion by the marine life; the COD depends on the kinetics of both sulfite dissolution and sulfite oxidation to sulfate.

The actual impacts of sulfite toxicity, dissolution and oxidation will require further investigation.

4. Trace contamination in wastes—Untreated and treated FGC wastes may contain several trace elements in concentrations in excess of acceptable levels for the marine environment. These elements include mercury, zinc, selenium, cadmium and nickel (among others). Significant dilution of the wastes with seawater (i.e., dispersion) may be necessary for ocean disposal to be acceptable.

In examining these environmental concerns, various methods of transportation and disposal of the FGC wastes were examined, including surface craft (e.g., bottom-dump barge and slurry dispersion) and pipeline (outfall). Various chemical and physical forms of the FGC wastes were also considered—i.e., sulfite-rich wastes, sulfate-rich wastes, and treated wastes in both "soil-like" and "brick-like" forms. Both Continental Shelf and deep ocean disposal of the wastes were examined from environmental, technical and economic standpoints.

As a result of the current study, several preliminary conclusions were drawn. Until more-definitive data are available, it would appear that disposal of sulfite-rich FGC wastes on the Continental Shelf or in the deep ocean would not be advisable. In addition, it appears that all soil-like FGC wastes—sulfite or sulfate, treated or untreated—should not be disposed of via quick-dumping surface craft or pipeline (outfall) on the Continental Shelf. Several other options appear more promising—all via surface craft:

1. Dispersed disposal of sulfate-rich FGC wastes on the Continental Shelf.
2. Concentrated disposal of treated, brick-like FGC wastes on the Continental Shelf.
3. Dispersed disposal of sulfate-rich FGC wastes in the deep ocean.
4. Concentrated disposal of both sulfate-rich and treated FGC wastes in the deep ocean.

Conclusions

Vast quantities of FGC wastes will be produced by coal-burning power plants in the mid-1980s. Although opportunities for utilization of these wastes will undoubtedly exist, disposal of FGC wastes will be practiced at most of the plants. Because of environmental concerns related to disposal of these wastes, several alternatives are being studied, including variations within each alternative. The alternatives are ponding, landfill disposal, mine disposal, and (possibly) ocean disposal. Ponding and landfill disposal are both current practices, but improvements in environmental protection and in costs associated with these methods are emerging through a combination of EPA and private-industry efforts. Mine disposal, particularly coal-mine disposal, of FGC wastes is being considered by private industry and, according to EPA studies to date, appears quite promising. Ocean disposal is currently under study and, although a degree of uncertainty exists regarding its viability, several approaches appear promising. All of these alternatives are being studied to encourage the environmentally acceptable use of domestic coal for power production.

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